FORMEC 2016
49th International Symposium on Forestry Mechanization
4-7 September 2016
Warsaw (Poland)

Arkadiusz Gendek, Jarosław Kikulski, Tadeusz Moskalik, Tomasz Nurek, Witold Zychowicz

LOGISTIC ANALYSIS OF WOOD PROCUREMENT CHAIN FROM FOREST TO POWER INDUSTRY PLANT

Warsaw University of Life Sciences - SGGW
Faculty of Production Engineering, Faculty of Forestry

The scope of study

Main (strategic) goal – optimization of biomass supply chain in north-east part of Poland.

Goal for next few years – optimization of forest energy biomass harvesting and transportation for selected enterprise.

Goal of this presentation - the characteristics of the process of wood chips harvesting for energy purposes.

Territorial reach of the study

Variants of the technological process

- **Variant W1 (forwarder + chipper)**

Logging residues were collected by the forwarder (suitable for transporting branches and tops), and then transported to the storage yard at forest road. Further branches were collected from the piles by self-propelled chipper, equipped with a bin for chips. After filling the bin, chipper was moving to the truck and chips were spilled out into semitrailer.

- **Variant W2 (chipper)**

Self-propelled chipper with chips bin was gathering logging residues directly from the ground. After filling the tank chipper was driving to the truck and chips were spilled into the semitrailer.

Machinery

Mobile chipper BRUKS 805.2 STC and Forwarder John Deere 1410D with tilting sides

Variants of the technological process

Variant 2 – branches arranged in long piles; wood harvested by harvester

Variant 1 – branches evenly spaced on ground; wood harvested manually (chain saws)

Variants of the technological process

Variant 1 – pile of residues formed by forwarder nearby forest road

Variant 1 – forwarder with cargo of forest residues

Chipper operation cycle

Operation cycle of chipper has been divided into the following components:

- t_1 - driving without load, from the place of unloading to the point of start of residues collection and chipping;
- t_2 - chipping, that includes a collection of the remains using a crane and the necessary movements of the machine;
- t_3 - driving back with a cargo (storage bin filled with wood chips) to the place of unloading, after the completion of chipping;
- t_4 - discharge, spillage of chips to truck semitrailer.

Calculation equations

The duration of the operating cycle

$$t_c = t_1 + t_2 + t_3 + t_4 \text{ [min]}$$

Operational productivity

$$W_O = \frac{V_Z \cdot 60}{t_c} \text{ [m}^3\text{/h]}$$

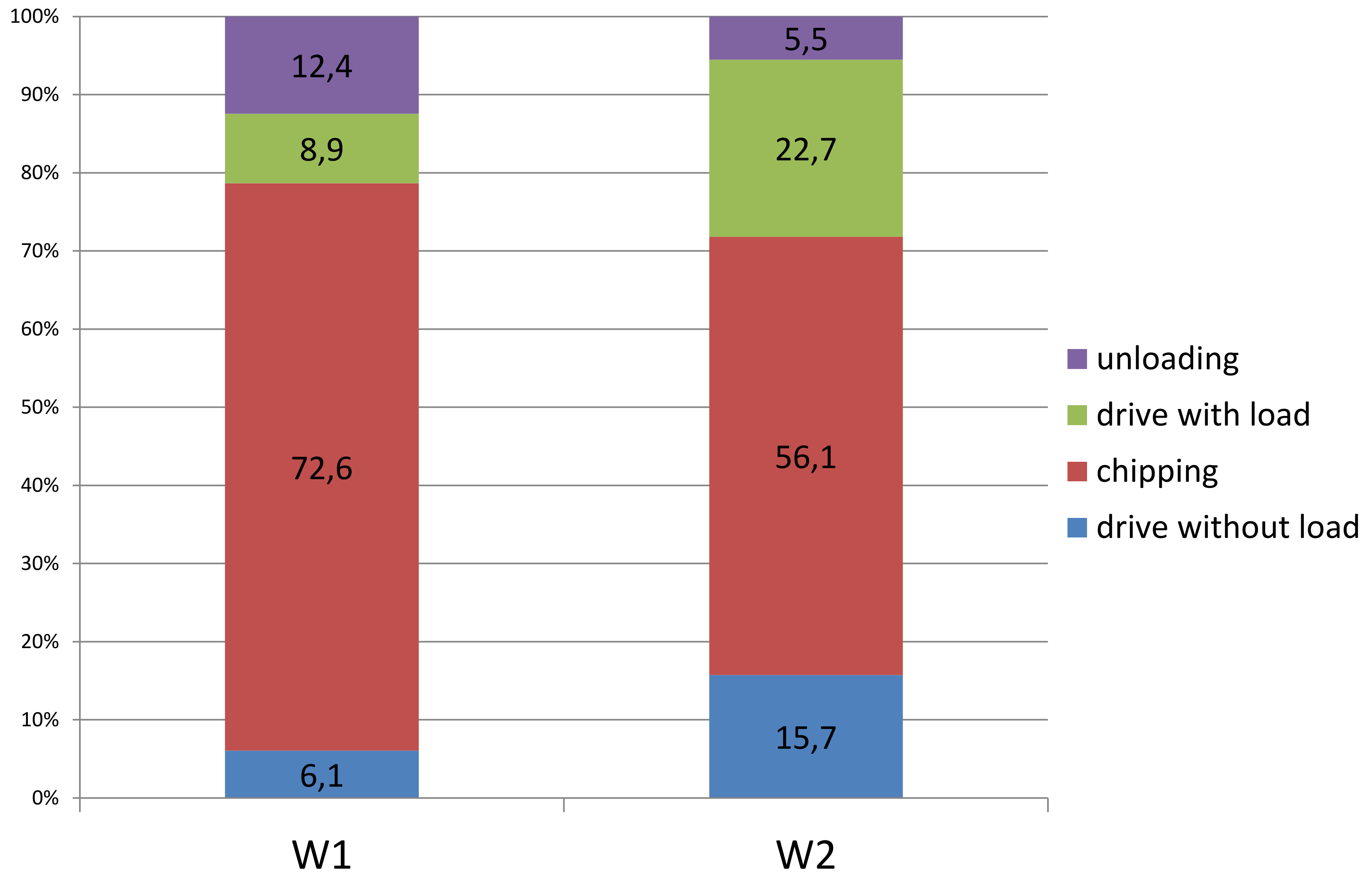
Chipping output

$$W_Z = \frac{V_Z \cdot 60}{t_2 + t_4} \text{ [m}^3\text{/h]}$$

The time structure of chipper operation cycle [min]

Technology	Average	Confidence -95%	Confidence +95%	Cycles	SD	SE	Min.	Max.
Driving without load								
W1	1,47	1,28	1,67	57	0,72	0,10	0,25	3,83
W2	6,19	5,26	7,13	27	2,37	0,46	0,90	11,52
All together	2,99	2,42	3,57	84	2,65	0,29	0,25	11,52
Chipping								
W1	17,63	15,54	19,71	57	7,86	1,04	4,50	42,23
W2	22,05	19,02	25,09	27	7,68	1,48	8,82	44,50
All together	19,05	17,31	20,79	84	8,03	0,88	4,50	44,50
Driving with load								
W1	2,16	1,81	2,50	57	1,29	0,17	0,33	6,08
W2	8,91	7,77	10,05	27	2,88	0,55	1,68	15,60
All together	4,33	3,52	5,13	84	3,71	0,41	0,33	15,60
Unloading								
W1	3,02	2,26	3,79	57	2,87	0,38	0,35	15,68
W2	2,17	1,51	2,83	27	1,67	0,32	0,72	6,97
All together	2,75	2,19	3,31	84	2,57	0,28	0,35	15,68
Cycle time								
W1	**24,28**	21,63	26,93	57	9,98	1,32	**8,08**	**61,05**
W2	**39,33**	34,75	43,90	27	11,57	2,23	**16,97**	**68,72**
All together	29,12	26,38	31,86	84	12,61	1,38	8,08	68,72

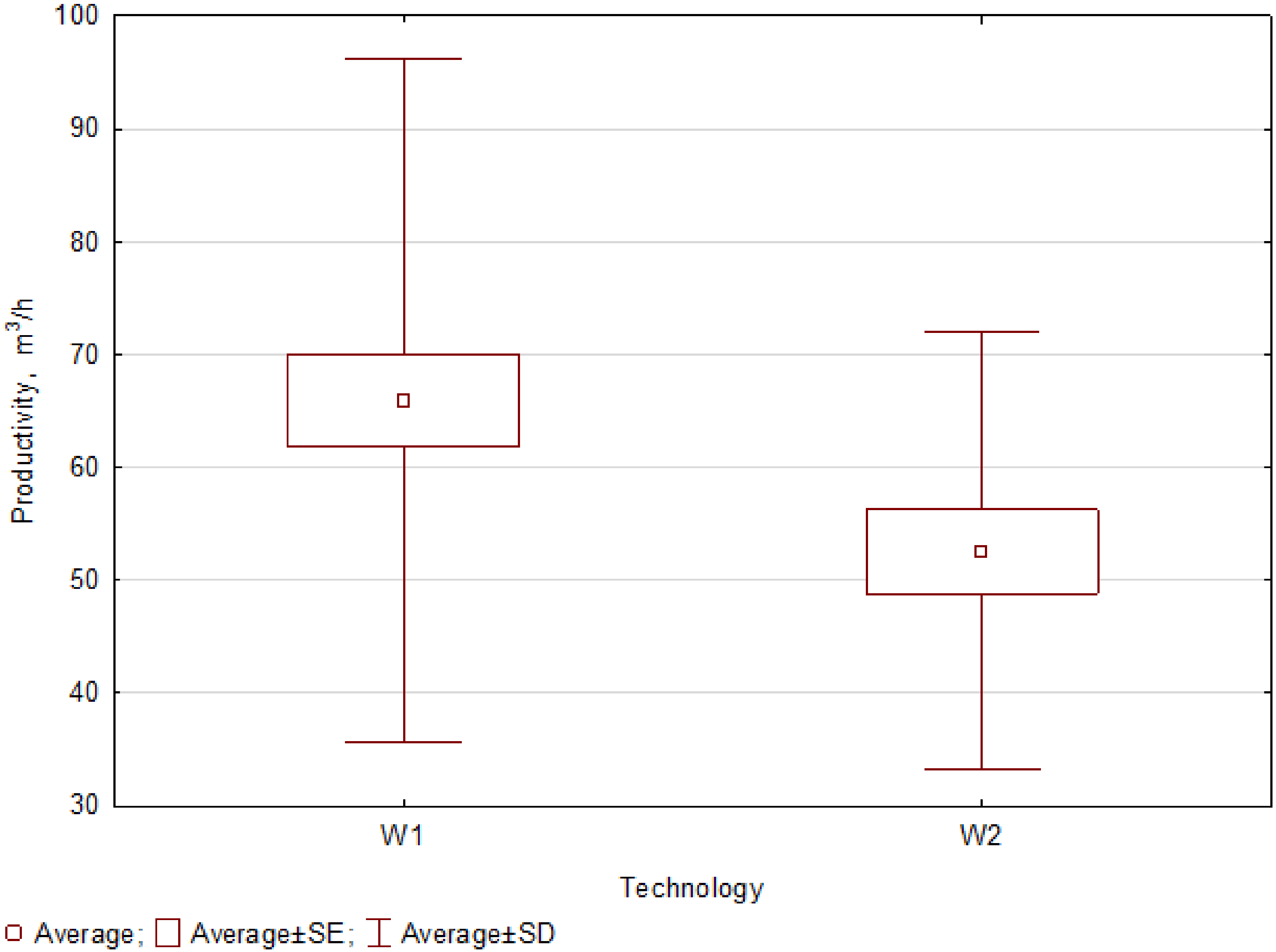
The percentage structure of chipper operation cycle [%]



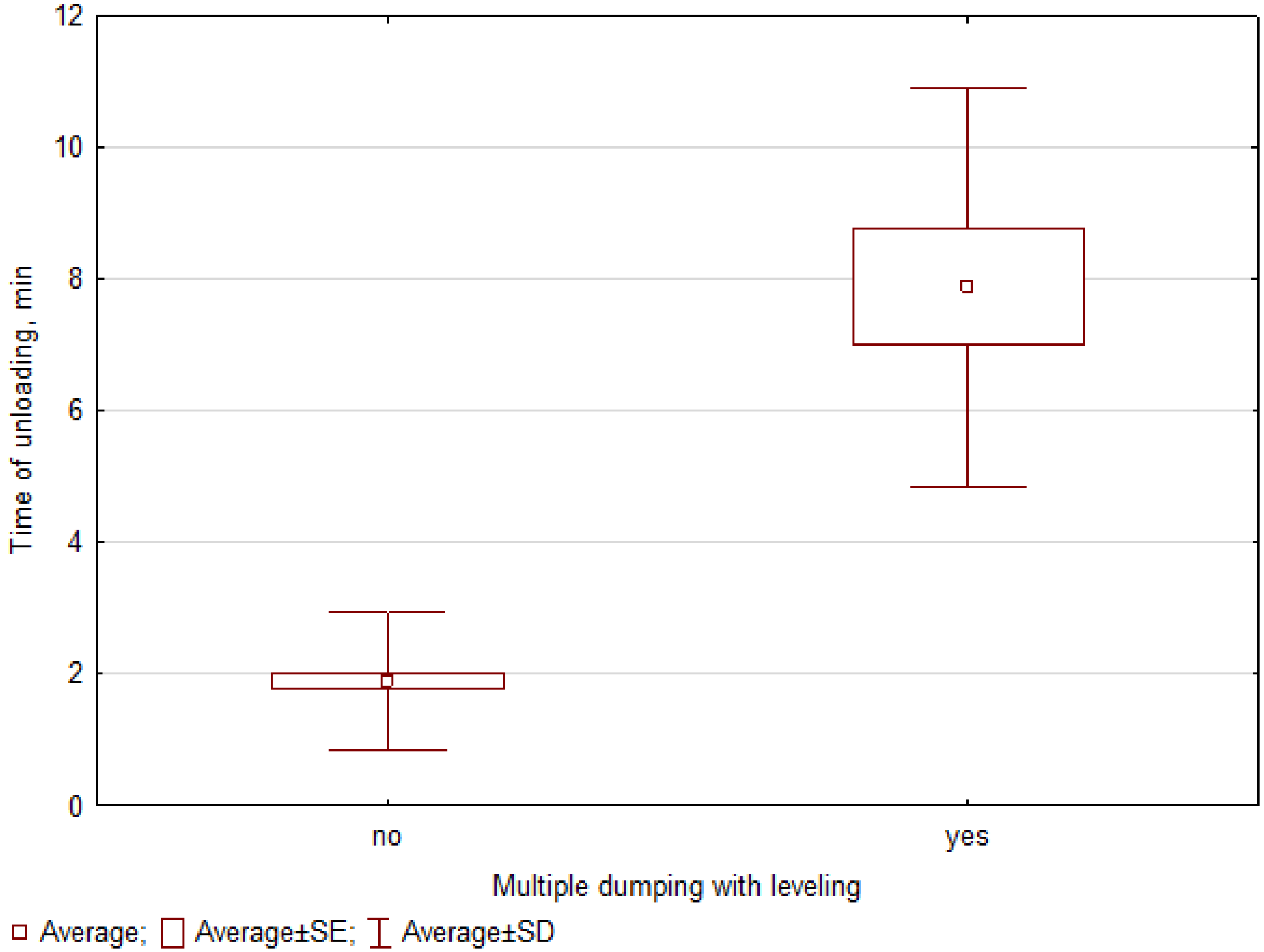
Chipper productivity [m^3/h]

Technology	Average	Confidence -95%	Confidence +95%	Cycles	SD	SE	Min.	Max.
Operational productivity (W_O)								
W1	**54,95**	48,79	61,11	57	23,22	3,08	**18,67**	**141,03**
W2	**32,25**	27,25	37,25	27	12,64	2,43	**16,59**	**67,19**
All together	47,65	42,67	52,64	84	22,97	2,51	16,59	141,03
Chipping productivity (W_Z, actual chipping and unloading)								
W1	**65,92**	57,88	73,95	57	30,27	4,01	**19,68**	**195,43**
W2	**52,58**	44,91	60,24	27	19,38	3,73	**25,05**	**98,13**
All together	61,63	55,59	67,67	84	27,84	3,04	19,68	195,43

The variability of chipper productivity



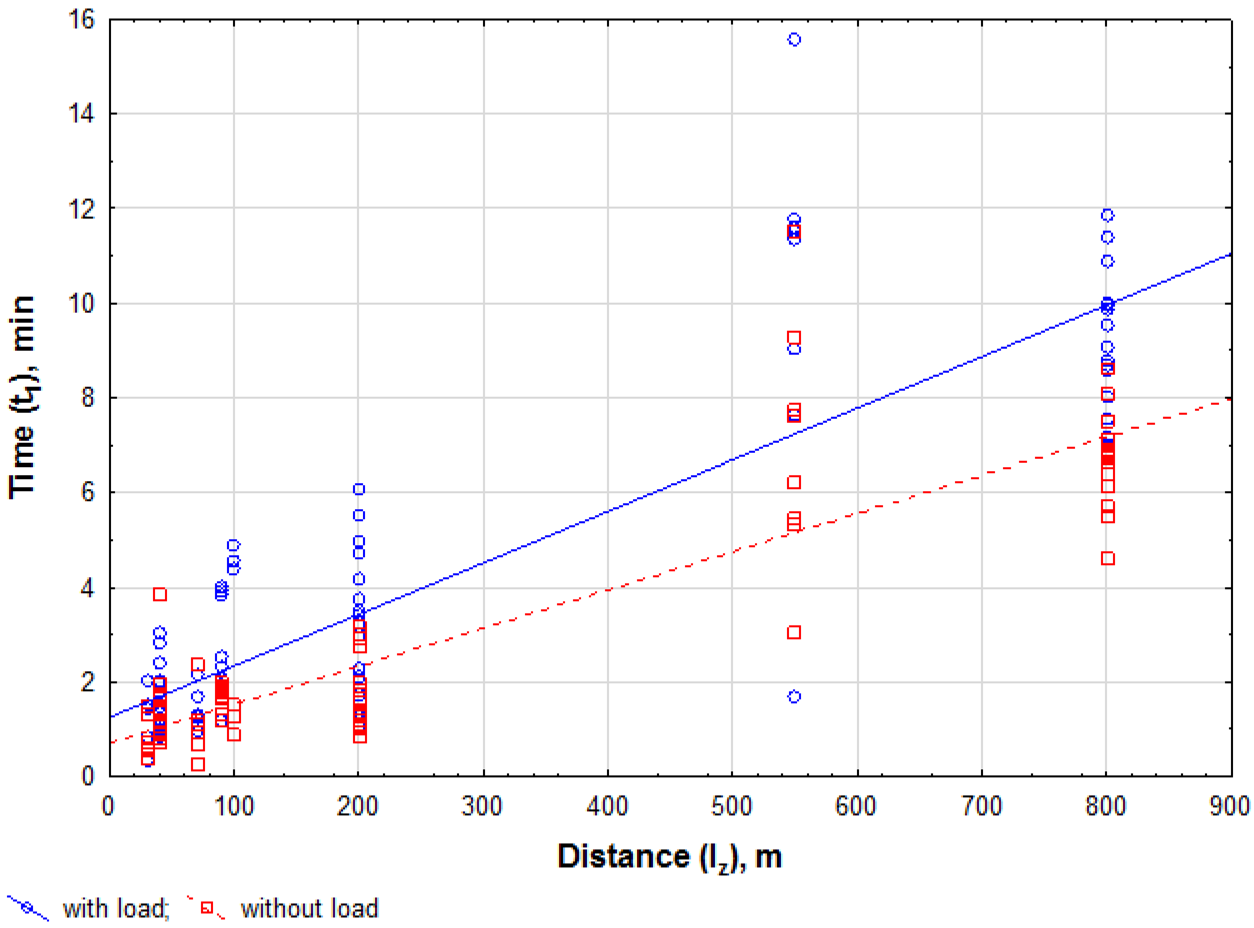
The comparison of chips dumping time



left
the entire container at one time

right
chips dumping spread over several stages with chips leveling using a crane

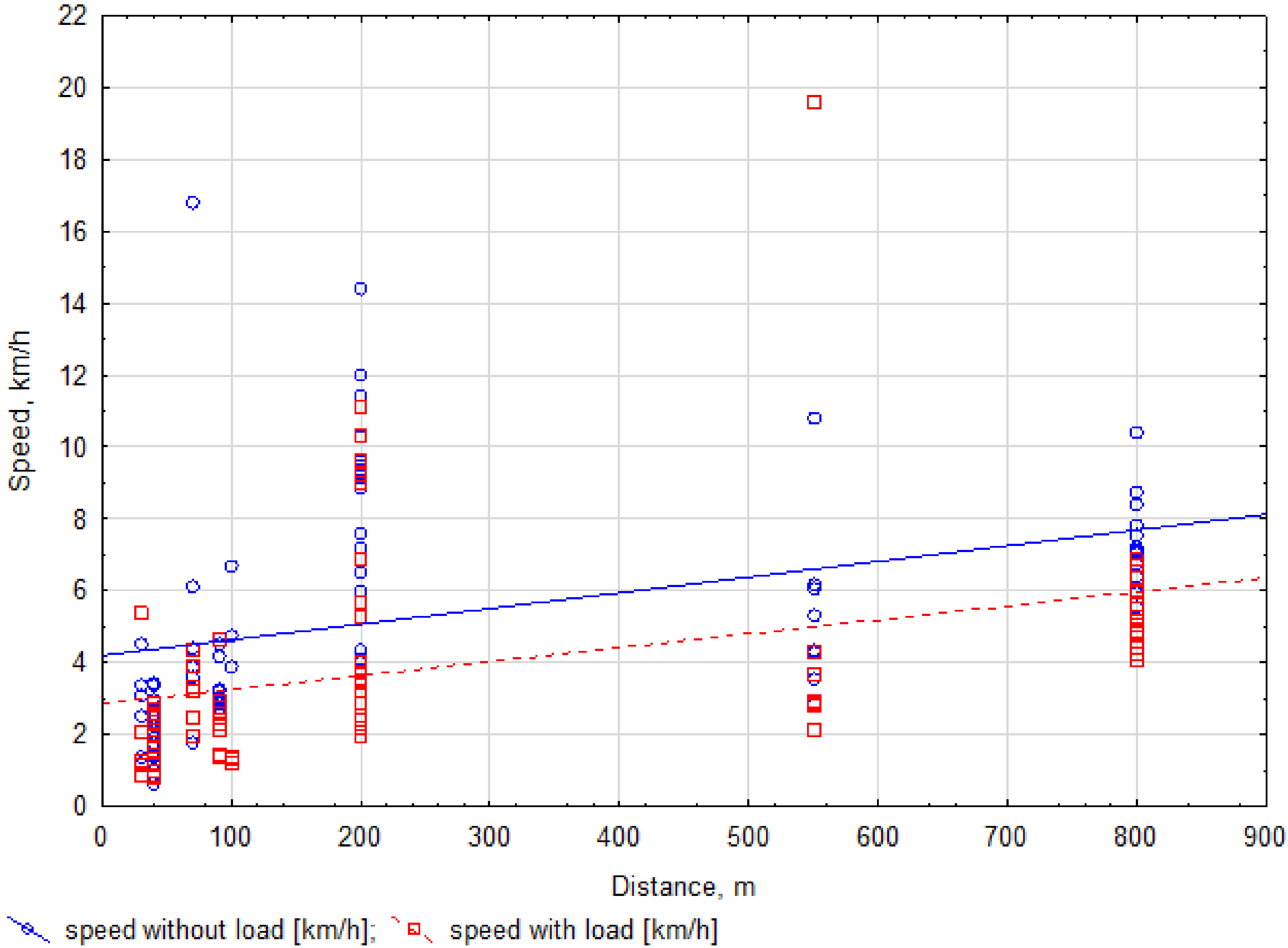
The dependence of chipper driving time on distance



Driving with load [min]: $t_3 = 1{,}2566 + 0{,}0109 \cdot l_z$; $r = 0{,}8491$; $r^2 = 0{,}7209$

Driving without load [min]: $t_1 = 0{,}7074 + 0{,}0081 \cdot l_z$; $r = 0{,}8846$; $r^2 = 0{,}7826$

Dependence of chipper speed on the distance



Dynamic programming

A typical description of the duration of the cycle (n) of operation (t_i)

$$t_i(n) = t_{mi}(n) + w_i(n) + p_i(n)$$

Duration of the process (T_i) after implementation of the n cycles

$$T_i(n) = T_i(n-1) + t_i(n) + z_i(n)$$

A key advantage of the method is the formal description of duration of interruptions (z_i) and thus the possibility of minimizing that time. The duration of the next (n) cycle of operations (t_i) results from the function describing the average duration (t_{mi}), function defining random deviation (w_i) and randomly occurring or planned downtime (p_i).

Dynamic programming

INTERRUPTION AT THE BEGINNING OF CYCLE

$$z'_i(n)=\begin{cases} T_{i-1}(n)-T_i(n-1), & if\ T_{i-1}(n)>T_{i-1}(n-1) \\ 0, & if\ T_{i-1}(n)\leq T_{i-1}(n-1) \end{cases}$$

INTERRUPTION AT THE END OF CYCLE

$$z''_i(n)=\begin{cases} T_{i+1}(n-1)-\left[T_i(n-1)+t_i(n)+z'_i(n)\right], \\ \qquad if\ \ T_{i+1}(n-1)>T_i(n-1)+t_i(n)+z'_i(n) \\ 0, \qquad if\ \ T_{i+1}(n-1)\leq T_i(n-1)+t_i(n)+z'_i(n) \end{cases}$$

Variant 2 - the variability of time of truck loading

The variability of operation cycle time [min]

Variant	Average	Minimum	Maximum
W2 (min – max)	39,33	16,97	68,72
W2 (± 95%)	39,33	34,75	43,90

Loading a truck requires 5 operation cycles of chipper. The last one contains multiple chip dumping and leveling.

The variability of time of truck loading [min]

Variant	Average	Minimum	Maximum
W2 (min – max)	196,7	90,9	337,5
W2 (± 95%)	196,7	179,8	213,5

Variant 1 - the variability of time of truck loading

The variability of chipper operation cycle time [min]

Variant	Average	Minimum	Maximum
W1 (min – max)	24,28	8,08	61,05
W1 (± 95%)	24,28	21,63	26,93

In the case of maintaining of the harvesting residues reserve of the appropriate size

The variability of time of truck loading [min]

Variant	Average	Minimum	Maximum
W1 (min – max)	121,4	46,4	299,3
W1 (± 95%)	121,4	114,2	128,7

Variant 1 - the variability of time of truck loading

The variability of forwarder operation cycle time [min]

Variant	Average	Minimum	Maximum
W1 (min – max)	34,48	29,47	41,15

The variability of machines productivity [m^3/h]

Machine	Average	Minimum	Maximum
Chipper	54,95	18,67	141,03
Forwarder	24,86	20,83	29,07

In case of absence of reserve of logging residues average time of truck loading can rise from **121,4** to **219,7** minutes

Productivity of forwarder was converted to the volume of loose chips using the conversion factor of 0.35.

Conclusions

It is recommended to use „variant 1 technology", due to the shorter time of truck loading and possibility of collecting residues from several forest areas in one place.

It is difficult to apply in forestry the method of description of uncertain dynamic systems derived from dynamic programming because of the need to collect large data sets. Only then it is possible to satisfactory fit probability distributions. Especially demanding is the description of the operation of transport vehicles for which the distribution parameters depend on the distances of transport.

This method can be very useful for quickly changing production processes carried out by machine groups consisting of at least several interacting units.

Thank you for your attention